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PRELIMINARY EVALUATION OF GLASS RESIN(TM)* MATERIALS FOR SOLAR CELL COVER USE

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ABSTRACT

Three readily available "off the shelf" Glass Resins(TM) applied on silicon solar cells and silicon wafers were evaluated for feasibility as solar cell covers by the Lewis Research Center. The Glass Resins(TM) ranging in thickness from about 8 to 40 μm were deposited by several techniques on 200-μm thick cells and on 50-μm thick wafers. The covered cells were exposed to ultraviolet (UV) light in vacuum at temperatures ranging from 50° to 160° C. The irradiation was performed at an intensity of 10 UV energy-equivalent solar constants at air mass zero for 728 hr. The exposure was followed by a single long thermal cycle from ambient temperature to -150° C. Visual inspection of the samples while still in vacuum, indicated that all samples had darkened to varying degrees but otherwise remained physically intact. The loss in short-circuit current was found to range from 8 to 24%, depending on the resin formulation. In another test over 40 Glass Resin(TM)-coated silicon wafers were subjected to thermal shock. All samples tested withstood 15 thermal cycles from 100° to -196° C in one or more of the thicknesses tested. Several of the resin-coated wafers were tested in a controlled relative humidity chamber at 65° C and 90% relative humidity for 170 hr. No change in physical appearance was detected during this test. The samples were visually inspected after each test.

INTRODUCTION

Previous work in printing of vitreous film protective coatings on silicon cells sponsored by the NASA-Lewis Research Center and performed by Owens-Illinois, Inc., showed that a heat-curable resin whose structure consists of alternating Si-O atoms (1) was a viable candidate for solar cell covers. The material, Glass Resin(TM) has physical, optical, electrical and thermal properties compatible with silicon and can be sprayed, dipped or spun onto surfaces. Because it can be applied in thin layers it is especially of interest for high power-to-weight ratio arrays which would be required for space missions in the Comet Ion/Drive class. The major damaging environment in such a mission is ultraviolet (UV) light at elevated temperatures followed by cold temperatures.

The objective of the work reported here was to determine the effect of such an environment on the physical integrity and performance of Glass Resin(TM)-covered silicon solar cells. Three "off the shelf" resins applied on 200-μm thick silicon cells and on 50-μm thick silicon wafers by several different techniques were subjected to three separate tests at the Lewis Research Center Laboratory. The resin coatings ranged in thickness from 10 to 40 μm. The covered cells were exposed in vacuum to UV irradiation equivalent to that which would be encountered during a Halley's Comet Rendezvous Ion Drive Mission. Coated wafers were subjected to a thermal shock test designed to cull out the weak candidates. In the third test several coated wafers were tested in a controlled relative humidity chamber for endurance in storage in a terrestrial environment.

EXPERIMENTAL APPARATUS AND PROCEDURE

The test to determine the physical integrity of the Glass Resin(TM) encapsulant under ultraviolet (UV) irradiation was conducted in 10^{-6} torr vacuum. The apparatus is equipped with two UV sources. One source consists of three medium pressure U-shaped lamps housed in Suprasil Quartz tubes which extend to the center of the vacuum chamber and the other of ten high pressure U-shaped lamps housed in a ring above a fused silica plate window at the top of the chamber. The detailed description of the apparatus can be found in another report of these Proceedings (2). Based on

*Trademark of product by Owens-Illinois, Inc.

measurements made at the position of the specimen holder for a previously conducted experiment (2), the combined intensity of the two sources was judged to be 10 air mass zero UV energy-equivalent solar constants. One air mass zero energy-equivalent solar constant was defined to be a UV intensity with total energy below the 0.4 μm wavelength equal to that below 0.4 μm in air mass zero sunlight. The samples were irradiated for 728 hours. At an intensity of 10 AMO UV energy-equivalent solar constants this irradiation time yields a UV dose approaching that which would be encountered in a Halley's Comet Rendezvous Ion Drive Mission.

Three types of Glass Resin(TM) coatings (GR100, GR650M, GR908M) were either spray-on spin-deposited by Pantek International Corp. on all samples for the three experiments conducted in thicknesses from about 8 to 40 μm. The coatings were deposited on the 200 μm thick solar cells and on the 50 μm thick silicon wafers. The samples irradiated in the UV chamber were held in place by individual clamps that were electrically insulated from the specimen holder. The uncovered cell with silicon monoxide antireflection coating was included in the test as a control cell.

Performance of the samples prior to and following the test was measured under an X-25 Xenon arc solar simulator. The intensity was set with a calibrated reference cell and temperature of the cells was maintained at 25° C during measurements. The spectral response of the samples was measured using the filter wheel spectral response equipment (3). Nine narrow band-pass monochromatic interference filters spanning the wavelengths range from 0.4 to 1.0 μm were used.

The specimen holder cooling could be adjusted to maintain the desired minimum 50° C temperature of the samples during the UV exposure. Different temperatures were achieved for some cells by mounting them on intermediate layers of Kapton. Several cells were instrumented with thermocouples and the following temperature ranges were measured during the irradiation:

(a) Specimen holder, 40° to 45° C.

(b) Bare control cell and most Glass Resin-covered cells, 50° to 56° C.

(c) One GR650M-covered cell, 75° to 82° C.

(d) One GR100-covered cell, 150° to 165° C.

After the irradiation the cells were subjected to a single thermal cycle as follows:

(a) Cooling from 30° to -150° C in about 30 minutes.

(b) Soak at -150° C for about 8 hr.

(c) Warming to 25° C in about 5 hr. The length of the periods during thermal cycle were selected to be short enough for experimental convenience, yet slow enough to be representative of changes during a mission of several year's duration such as the Halley's Comet Rendezvous.

Following the thermal cycle the samples were taken out of the vacuum chamber and placed into a container flushed and back-filled with dry nitrogen and transported for measurements and evaluation under the X-25 solar simulator and the filter wheel simulator.

Over 40 resin-coated silicon wafers were subjected to thermal shock. The wafers ranged in thickness from 50 to 200 μm and the coatings ranged in thickness from 8 to 40 μm. These samples were given 15 temperature cycles from 100° to -196° C with 15 to 20 second cool-down and 4 to 5 minute heat-up times. The samples were held between stainless-steel screens, heated in air to 100° C and quickly immersed in liquid nitrogen. This was a severe test designed to quickly identify the problem areas rather than reflect true outer space environmental conditions.

Nine silicon wafers representative of samples used in the thermal shock test were tested in a controlled relative humidity chamber for 170 hr. Test conditions were 65° C at 90% relative humidity. Samples were visually inspected for color change, evidence of peeling, blistering, etc.

RESULTS AND DISCUSSION

Visual inspection of the samples after the UV exposure test, while still in vacuum, indicated that all samples had darkened to varying degrees with GR100 being the least darkened. Half of the GR650M samples had a milky appearance, the rest were clear but darker than the GR100 samples. Cracks in several cells which were introduced either during pre-irradiation measurements or during mounting of samples on the specimen holder showed no change. Following the thermal cycle the samples were inspected while still in the vacuum and then more closely after being transferred to a dry nitrogen atmosphere. The results were essentially the same as immediately after the UV exposure. During the disassembly from the specimen holder some of the previously noted cracks increased in severity and in one case a portion of the cell became separated. These physical conditions could have affected the post-irradiation measurements.

The exposed surfaces of the mounting block were covered with a light blue coating, whose source is unknown. The uncovered control cell showed a change in color of the exposed silicon monoxide antireflection

coating and the spectral response measurements indicated a slight shift in response toward longer wavelength. Such an effect is indicative of a thicker antireflection coating (4). However, the measurement of the overall response of this cell showed a 5% decrease in short circuit current. The decrease was unaffected by cleaning of the cell with alcohol. It is assumed that the 5% reduction in short circuit current of the uncovered control cell is due to the noted coating and that the rest of the samples lost the same fraction of their current due to a similar coating. Therefore, the current loss for the other samples was corrected (decreased) by 5%.

Corrected measurements in percent loss of short circuit current for the resin-coated cells at various resin thicknesses are shown in figure 1. These results indicate that all samples suffered loss of short circuit current with GR100 showing the lowest (from 8 to 12%) and GR650M the highest (from 22 to 24%) losses. The loss appears to be a function of thickness of the coating for GR100 and GR650M. Whether the same would hold true for GR908M cannot be ascertained since only two samples with this coating were tested. This apparent trend is the reverse of an expected effect, namely thicker coatings darkening more.

The GR100 sample 21-μm thick was held at a temperature around 150° C during irradiation, and exhibited a slightly higher (2 to 3%) degradation. A portion of one cell coated with GR650M, 20-μm thick, broke during disassembly and its post-irradiation short circuit performance was calculated from the measured portion.

Current-voltage and spectral response curves of the cell coated with 40-μm thick GR100 resin are shown in figures 2 and 3. Qualitatively these are typical of all Glass-Resin-coated cells in this test, indicating general darkening of the cell cover with higher losses in the blue portion of the light spectrum.

It must be recognized that in the UV exposure test it is not known how well the energy-equivalent exposure reproduces the same damage as natural space sunlight. Space flight experiments have long been needed to relate such ground tests to space UV exposure.

The results of the thermal shock tests are summarized in figure 4. All resins tested withstood 15 thermal shocks from 100° to -196° C in one or more thicknesses tested. The resin thickness at which a material failed depended on resin composition. The GR100 suffered no damage only at the 10 μm thickness. The resins GR908M and GR650M withstood the tests in thicker layers. These were formulated by the manufacturer to give a better match between the coefficients of linear expansion of the resin and the silicon and therefore a lower internal stress. However, it should also be noted that the modification which apparently provided better physical compatibility with the cell also caused greater darkening due to UV evidenced by the greater loss in short circuit current (fig. 1).

The samples showed no change in physical appearance after the humidity test except that one wafer developed two small chips about 0.8 mm square. The cause of these chips is unknown.

SUMMARY OF RESULTS

A preliminary investigation was conducted in which silicon solar cells and silicon wafers covered with "off the shelf" Glass Resins(TM) were subjected to three tests: UV irradiation in vacuum at an intensity of 10 air mass zero UV energy-equivalent solar constants for 728 hr followed by a long thermal cycle; 15 thermal shock cycles between 100° C and -196° C; and temperature humidity (65° C at 90% relative humidity).

The following results were obtained from these tests:

(a) The UV exposure caused darkening of the covers and a loss in short-circuit current from about 8% to about 24% depending on the composition of the Glass Resin(TM). The unmodified resin GR100 showing the lowest loss.

(b) Modification of Glass Resin(TM) to attain a better match between the coefficients of expansion of the resin and silicon results in better resistance to thermal shock. However, for the resin formulations tested the modification increases the darkening caused by UV irradiation.

(c) Glass Resin(TM)-coated silicon wafers were not damaged by the temperature/humidity test.

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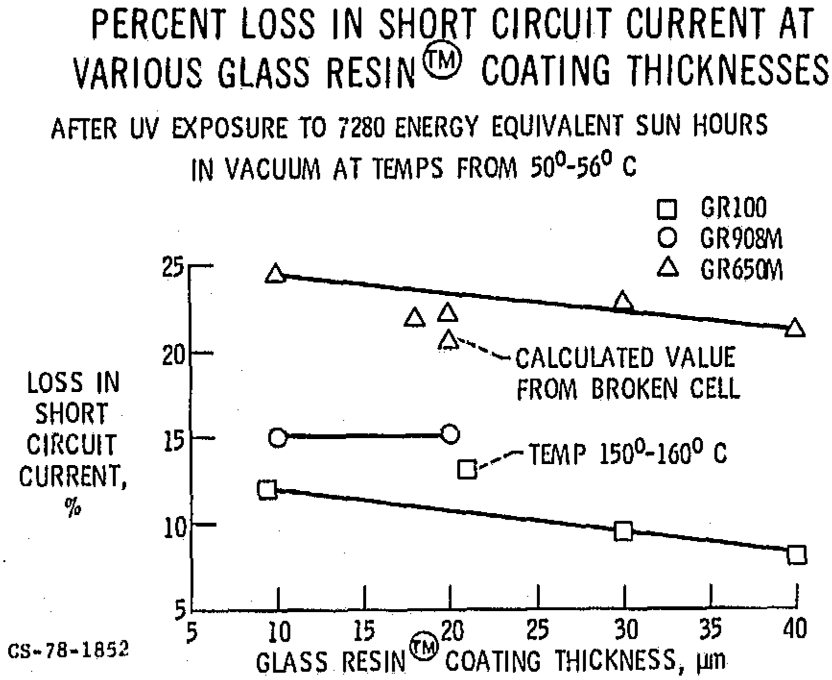
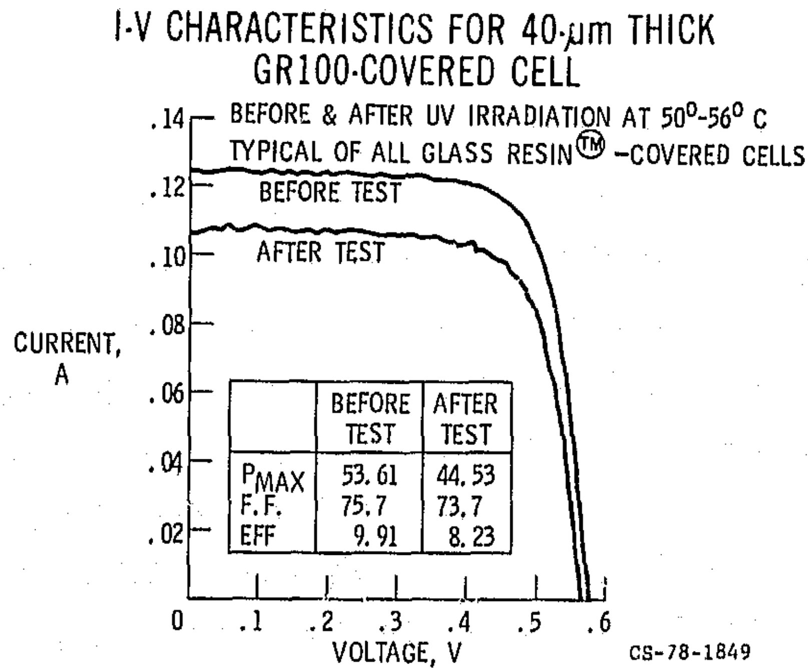


Figure 1.



	BEFORE TEST	AFTER TEST
P_{MAX}	53.61	44.53
F.F.	75.7	73.7
EFF	9.91	8.23

Figure 2.

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SPECTRAL RESPONSE FOR 40-μm THICK GR100-COVERED CELL

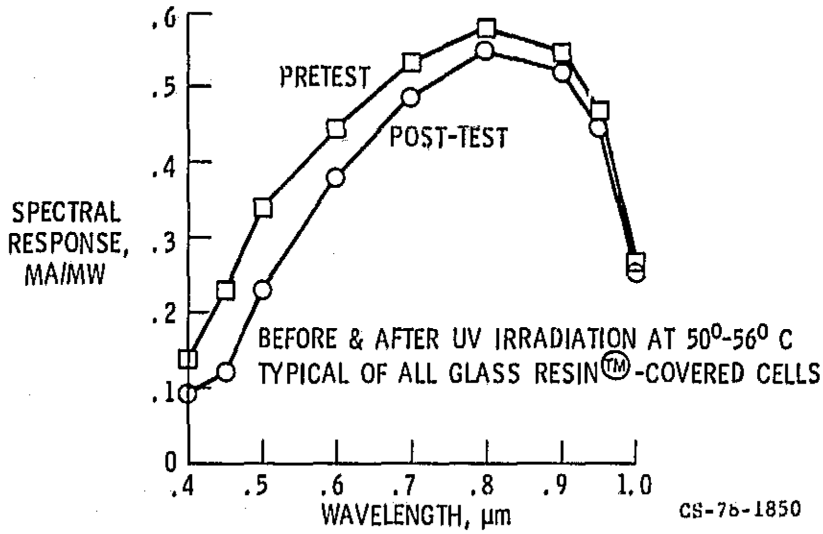

Figure 3.

RESISTANCE TO THERMAL SHOCK OF GLASS RESIN(TM) COATINGS OF VARIOUS THICKNESSES

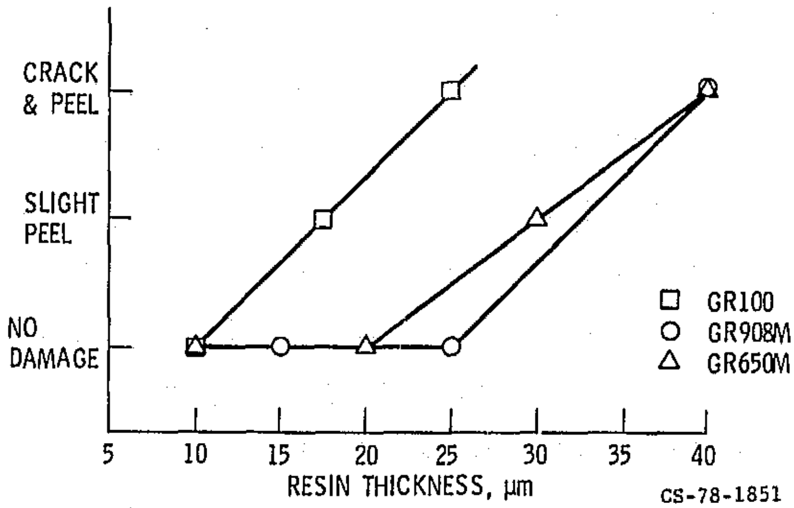

Figure 4.

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